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- **Inflatable space stations**
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Inside NASA's bold mission to find life

# What is a black hole?

All sorts of weird and wonderful things can happen when a star dies, such as neutron stars and white dwarfs. Undoubtedly the weirdest of them all, however, are the birth of stellar black holes. Like all the best enigmas of the universe, black holes are as misunderstood as they are mysterious and as hard to observe as they are to comprehend.

Stellar black holes are most commonly formed from the remnants of particularly massive stars when they die – their cores collapsing with a staggering force that defies our understanding of the laws of physics. As the star's mass is forced into an ever-smaller space, the gravitational forces involved effectively rips a hole in the fabric of the universe creating a singularity – the point at which all calculations break down, resulting in infinite loop instead of a number. The end result? The total and utter annihilation of matter and an 'ERROR' screen on the physicist's calculator.

**Spherical holes**
Although it's easier to visualise them as cosmic plugholes, black holes exist in four dimensions (the usual three, plus time), so they'd actually look like a ball, rather than a disc.

**Event Horizon**
The lip of the black hole separating the chaos below from the relative safety of the rest of the universe is called the Event Horizon. It's the point of no return that even photons can't outrun.

**Feeding frenzy**
The space approaching the Event Horizon of a black hole isn't as dark as you might think – as particles of matter spiral in, friction heats them to astronomical temperatures.

**Size is relative**
Black holes come in all sizes: stellar (up to 20 times the mass of the Sun), supermassive (millions of solar masses, found at the heart of galaxies) and microscopic. As small as a single atom, super-tiny black holes with the mass of Mount Everest are thought to have formed at the beginning of the universe.

# How the universe will end

Without the theory of the Big Bang we wouldn't have much to go on when it comes to estimating what the fate of the universe may be. Thankfully, we can come up with several theories for how the universe might end based on our observations of the cosmos, namely that it appears to be expanding at an accelerating rate, but some theories suggest this won't be the case forever.

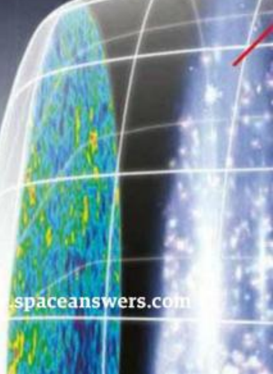
For example, the False Vacuum theory states that a so-called 'metastability event' could cause the vacuum of space to 'ping' into a lower energy state changing the rules of space, time and matter. If this is the case the entire universe could end at any moment.

Other popular views on when and how the universe will end include the Big Crunch, which is the theory that the universe will eventually start shrinking back to a singularity and re-spawn a new universe, possibly signifying the endless cycle of our universe's life and death.

There is also the Big Rip theory, where the expansion of the universe would continue to accelerate at such a rate that all the matter would be forcibly ripped apart at the seams.

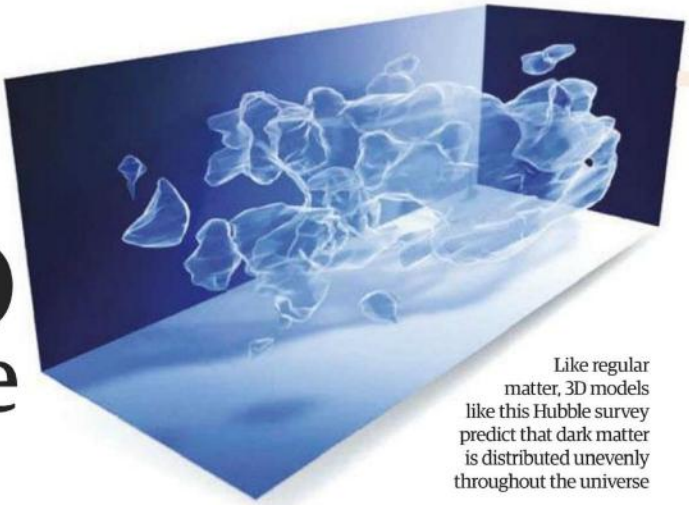
However, the most popular of all current theories is the Big Freeze, which simply dictates that the expansion – and cooling – of the universe will continue unabated until everything in it reaches 'absolute zero'. At this point the universe would cease to move and would become stable, possibly existing forever.

Either that, or our universe could actually be a multiverse and every other possible end to the universe could quite feasibly be happening right now. Since a multiverse of infinite 'verses' would require infinite space and energy, the multiverse would never cease to exist.



**Start: The Big Bang**
During the first 10-32 seconds following the Big Bang, tiny quantum fluctuations ballooned into a size where they would have been visible to the human eye.

# 96% of universe is missing



Like regular matter, 3D models like this Hubble survey predict that dark matter is distributed unevenly throughout the universe

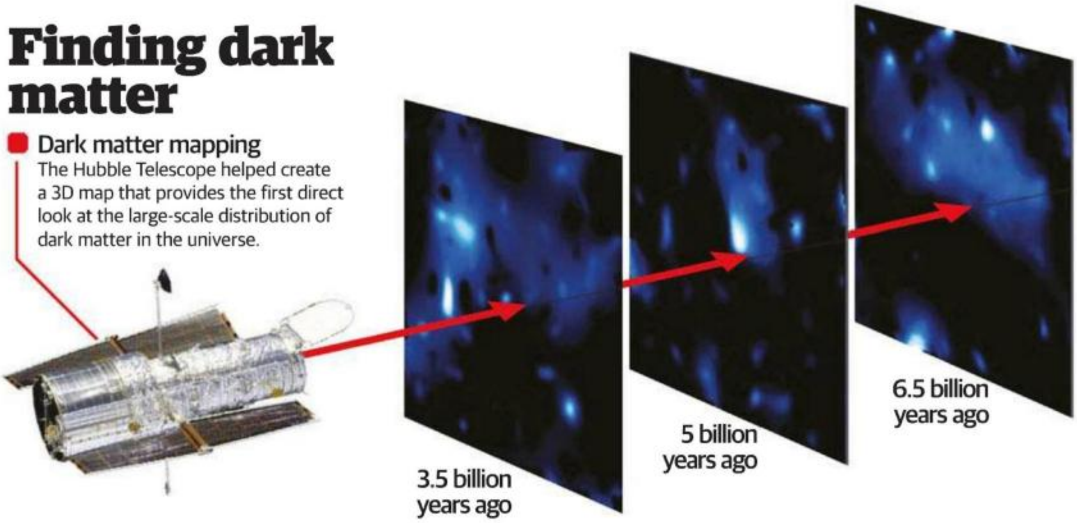
The chilling discovery came to light in the Nineties when astronomers realised the universe's expansion was accelerating instead of slowing, as they'd predicted.

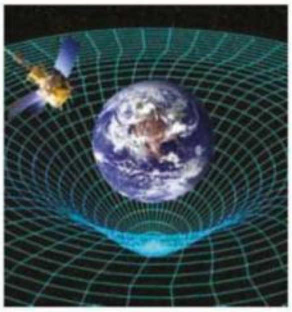
So little is currently known about the mystery, the term 'dark matter' effectively exists as a placeholder - a means to explain an unfathomable problem in a barely more comprehensible way. Thanks to more recent discoveries we do at least have a rough idea of where dark matter resides.

The globular image above depicts the distribution of dark matter across the universe. The COSMOS survey, a Hubble project studying the relationship between large scale structure (LSS) in the universe and dark matter, as well as the formation of galaxies - has offered the most compelling evidence yet that known matter tends to cohabit the same space as the densest concentrations of dark matter. Just don't ask anyone what it is... ■

## Finding dark matter

**Dark matter mapping**
The Hubble Telescope helped create a 3D map that provides the first direct look at the large-scale distribution of dark matter in the universe.





## Gravity cannot be explained

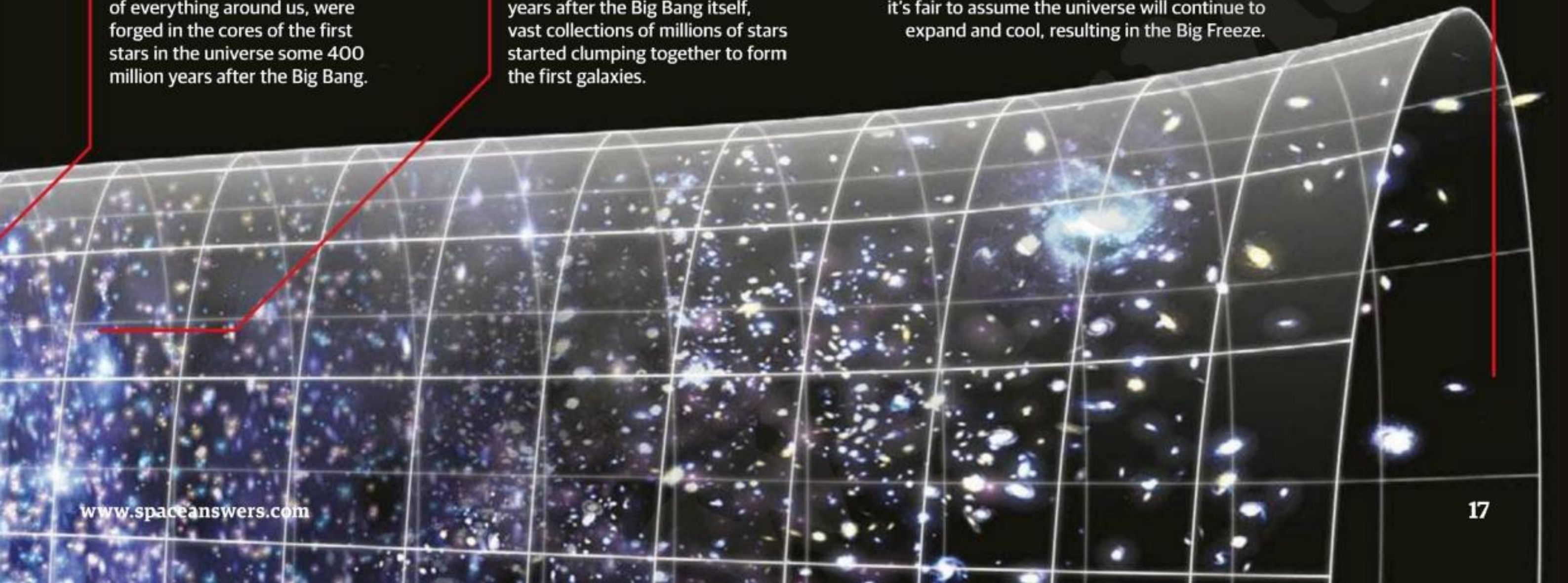
Gravity is a mind-boggling conundrum. Despite being able to predict its effect with enough scientific accuracy to chart the locations of celestial bodies millions of years into the future, we haven't yet entirely grasped what makes it work.

We know that gravity operates at the speed of light and attracts clumps of matter with a force directly proportional to their mass and is unlike the other three forces of nature, because it has a fundamental relationship with time and space. What we don't know is what particles are actually responsible for creating the force of gravity. Researchers at particle accelerators on Earth like the Large Hadron Collider near Geneva, Switzerland are hoping to find the answer soon.

**First light**
The first heavy elements, essential for the construction of everything around us, were forged in the cores of the first stars in the universe some 400 million years after the Big Bang.

**One billion years on**
Another half a billion years on from the first stars, and a billion years after the Big Bang itself, vast collections of millions of stars started clumping together to form the first galaxies.

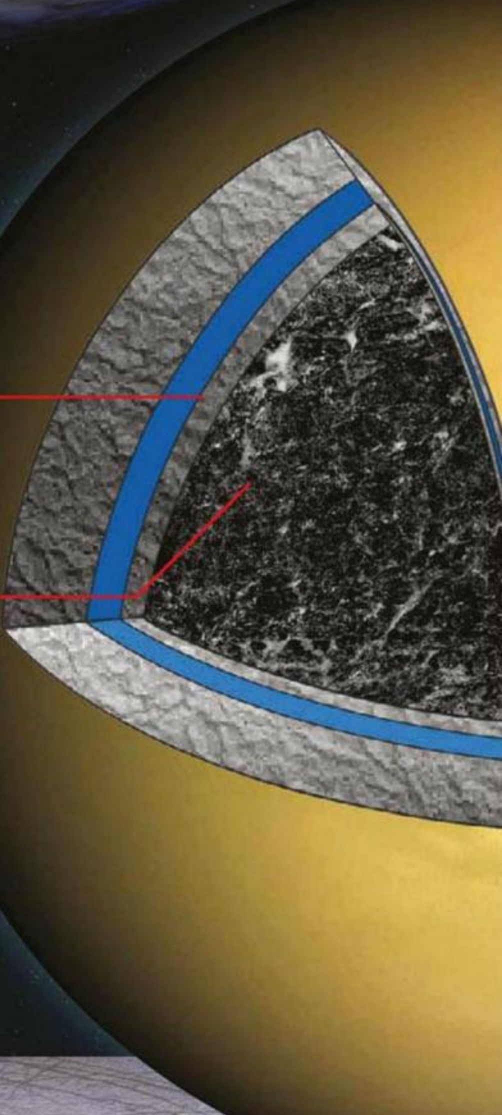
**The end: What happens next?**
What comes next may never be truly understood, but according to one generally accepted model, it's fair to assume the universe will continue to expand and cool, resulting in the Big Freeze.



# Discovering life on Jupiter

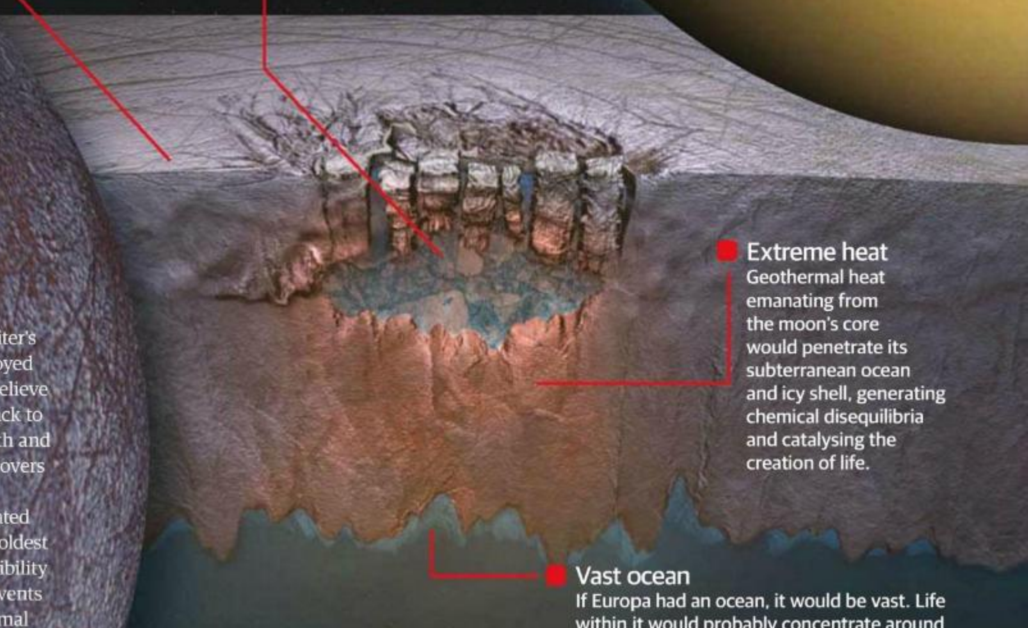
The JUICE spacecraft (Jupiter Icy Moon Explorer) – is arguably the most exciting development yet in the search for alien life. The European Space Agency spacecraft, which was selected above a host of rivals for the crucial mission, is due to head to the Jupiter system in 2022 in search of new life forms. Launching on the back of the extremely powerful Ariane 5 rocket, JUICE will engage its solar-powered electric engines and make the long-haul, eight-year flight to Jupiter. Upon arriving, JUICE will analyse the planet, as well as its icy moons Europa, Callisto and – most importantly – Ganymede. Ganymede will be the focus of its 1.4GB daily data downlink as reports indicate that it contains a subsurface ocean. If this is true, then that ocean could be the location of our very first contact with an alien organism.

**JUICE**
The possibility of finding alien life on Ganymede is the main focus of JUICE's mission to Jupiter.



**Life-bearing ocean?**
There is a strong chance that Titan has a life-bearing underground ocean of water and liquid ammonia roughly 200km (124 miles) beneath its surface.

**Silicate core**
Reports indicate that Titan has a silicate core and that its interior may still be hot, with a layer of magma-like material composed of water and ammonia generating heat.



**Young crust**
Europa's surface is largely crater-free. This leads scientists to believe that it is relatively young and could harbour underground oceans and lakes.

**Underground lakes**
In addition to a vast underground ocean, studies have shown that huge liquid lakes could also exist, entirely encased within Europa's icy shell.

**Extreme heat**
Geothermal heat emanating from the moon's core would penetrate its subterranean ocean and icy shell, generating chemical disequilibria and catalysing the creation of life.

**Vast ocean**
If Europa had an ocean, it would be vast. Life within it would probably concentrate around hydrothermal vents on the ocean floor, or cling to the lower surface of its icy shell.

# Underground oceans of Europa

While primarily being sent to search for alien life on Jupiter's moon Ganymede, the JUICE spacecraft will also be deployed to Europa. The reason? Scientists at NASA and the ESA believe it could also harbour life. Indeed every report beamed back to Earth to date has indicated that due to the moon's smooth and youthful surface, there is an excellent possibility that it covers a vast subterranean ocean.

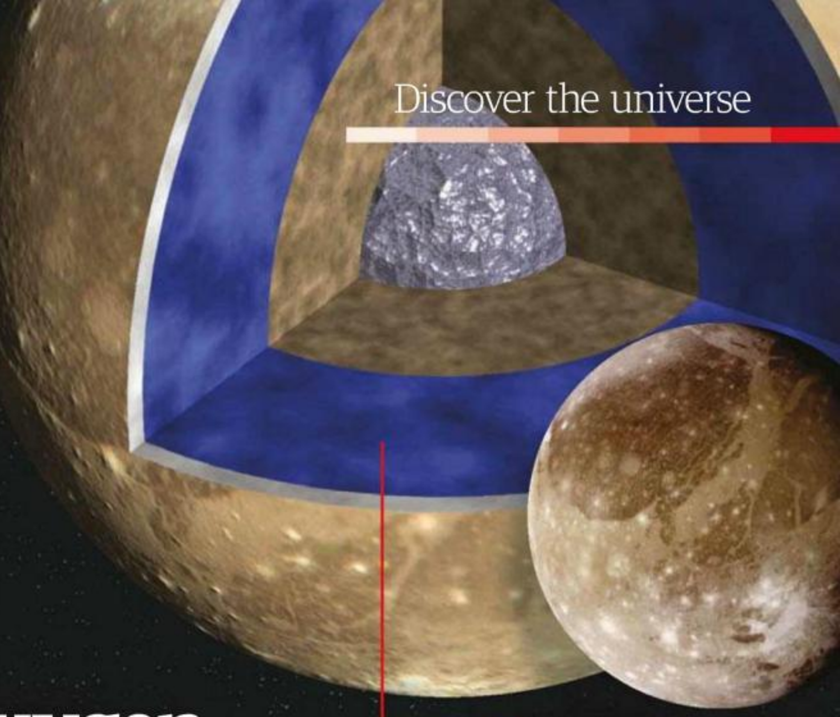
If there is an ocean under Europa, then – as demonstrated in missions down to the bottom of Earth's deepest and coldest oceans, where microbial life is abundant – there is a possibility that some form of life could exist as deep hydrothermal vents emanating up from the moon's core could inject geothermal energy into the waters, providing the catalyst to the creation of life.

**Earth-like surface**
Titan's surface is Earth-like, with rivers and lakes of liquid ethane and/or methane potentially providing habitats for non-water-based life forms.

**Atmosphere**
Much like its surface, Titan's atmosphere is also very Earth-like. It is dense, chemically active and is privy to weather such as cloud formations and rain.

# Titan's Earth-like climate

Saturn's moon Titan is incredibly interesting because it has a dense nitrogen-rich atmosphere and a climate similar to that on Earth, with wind, rain and clouds a frequent occurrence. Indeed, its surface even has similar features, too, such as sand dunes, rivers, lakes and seas - although the latter's 'water' is most likely liquid methane and ethane. As such, it is thought by scientists to potentially be a habitat in which microbial extraterrestrial life could survive, or at the very least, act as a rich prebiotic environment for their future creation. ■



**Going deeper**
Ganymede has a cold rigid ice crust, an outer warm ice mantle, an inner silicate mantle and a metallic core.

# Oxygen on Ganymede

Reports indicate that oxygen may exist within the atmosphere of Jupiter's Ganymede moon. The oxygen is created when water ice on the moon's surface is split into hydrogen and oxygen by impacting radiation waves, with the hydrogen then proceeding to be lost from the atmosphere quicker than the oxygen due to its low atomic mass. This process leaves a thin layer that includes oxygen, oxygen gas and ozone. Importantly, however, the presence of oxygen is not direct evidence that there could be life on Ganymede, rather just an extra layer of chemical complexity in which life could, theoretically, be generated. However, the oxygen concentrations on Ganymede are roughly equivalent to those found on Mars, a planet on which scientists believe life could have existed at one time. ■

# Life in the methane lakes?

One of the best chances of finding life on Titan is within its numerous, large methane lakes. These lakes, which litter the moon's surface, could act as our water-based ones do on Earth.

Critically, however, for this to be possible it would require the alien organism to intake hydrogen rather than oxygen, react it with acetylene instead of glucose and produce methane instead of carbon dioxide.

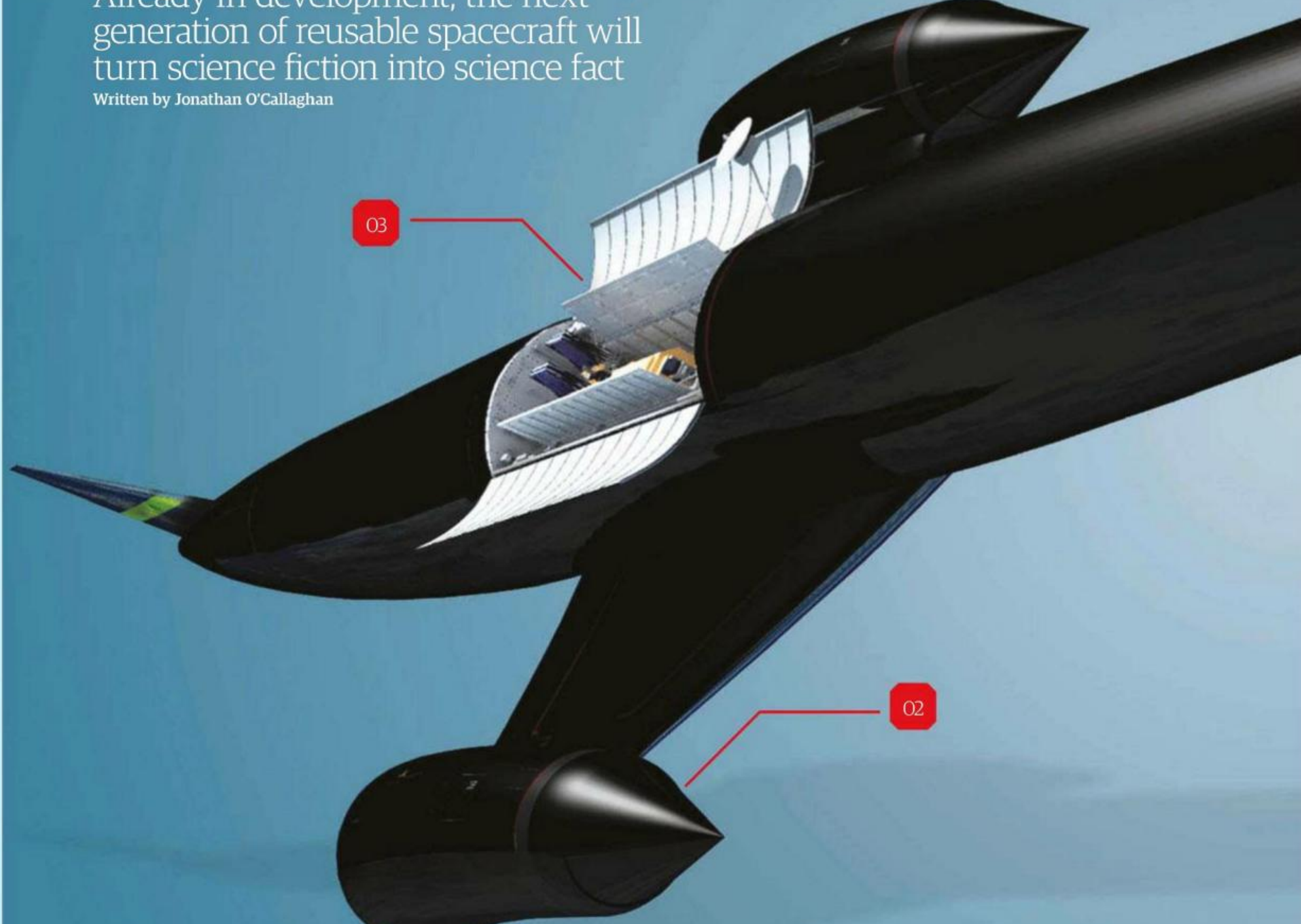
While sounding far-fetched, it becomes more of a reality when you consider that there are various methanogens (methane-producing microorganisms) on Earth that obtain their energy by reacting hydrogen with carbon dioxide in a very similar way. ■

Bodies of liquid ethane and methane have been detected on Titan by the Cassini-Huygens space probe

# Space planes of tomorrow

Already in development, the next generation of reusable spacecraft will turn science fiction into science fact

**Written by Jonathan O'Callaghan**



"The impact of Skylon on the space business is going to far exceed any revolution in the aircraft industry"

### 1. Aerodynamic

Control of Skylon is provided by various aerodynamic components. Its tail fin can move to change the yaw of the vehicle, while the two small fins at the front alter the pitch. The wings, as well as providing lift, also offer roll control. The overall sleek design allows Skylon to attain orbital speed without being hindered by atmospheric drag.

# Skylon

## Great Britain's forerunner in the race for SSTO

**Company:** Reaction Engines Ltd
**Launch date:** 2018
**Cost:** $12bn **Length:** 82m (269ft)
**Wingspan:** 25m (82ft)

Skylon is one of the most promising of the space planes currently being developed, with more than $544m invested to date and an initial test flight planned for 2018. It's a single-stage-to-orbit (SSTO) craft designed to take off without boosters and accelerate into a stable orbit before deploying its payload and returning.

The problem with SSTO is that the vehicles ideally need to use air-breathing engines like a jet within the Earth's atmosphere, but once they are in the vacuum of space they must rely on a new method of propulsion. Richard Varvill, the technical director and chief designer at Reaction Engines Ltd, told us that Skylon aims to tackle this problem head-on: "The unique feature of Skylon is SABRE. The same engine can burn the hydrogen fuel with either air when it is within the atmosphere or with liquid oxygen when it is in space. This allows Skylon to fly to 25km [15.5 miles] altitude and a speed of over five times the speed of sound while consuming relatively small amounts of liquid hydrogen. When it switches to rocket mode Skylon has only 80 per cent of the work to do compared to a rocket taking off from the ground and this makes a big difference in the feasibility of the vehicle."

So, when will Skylon take to the skies? "With adequate funding we could plan a development programme with the first orbital test flight in 2018 followed by a further 403 test flights," said Varvill. "Skylon would then go into operational service in 2020."

### 2. SABRE

Skylon's revolutionary Synergistic Air-Breathing Rocket Engine (SABRE) uses both a jet-like air-breathing cycle and a pre-cooler heat exchanger to travel to and from the edge of space. Once airborne Skylon switches to rocket mode at a height of 25km (15.5 miles), accelerating to over 28,150kph (17,500mph) to reach Low Earth Orbit.

### 3. Cargo

It is currently planned that each Skylon vehicle will be unmanned and autonomous for the first few years of operation, but the ultimate goal is that for later flights it will be able to take humans into orbit. To do this, Skylon would carry a Personnel/Logistics Module, which could carry 24 passengers and a pilot.

### 4. Angle

Skylon will fly at a slight angle in order to generate lift. For this reason the engine intake of the nacelles is curved seven degrees downwards to ensure sufficient air is taken in. At the back of the nacelle the thrust chambers are again pointed down by seven degrees to ensure that they point through the centre of mass of the vehicle.

# Dream Chaser

## Vertical-take-off space plane ready to launch in 2014

**Company:** Sierra Nevada Corporation
**Launch date:** 2014
**Cost:** $1bn **Length:** 9m (30ft)
**Wingspan:** 7m (23ft)

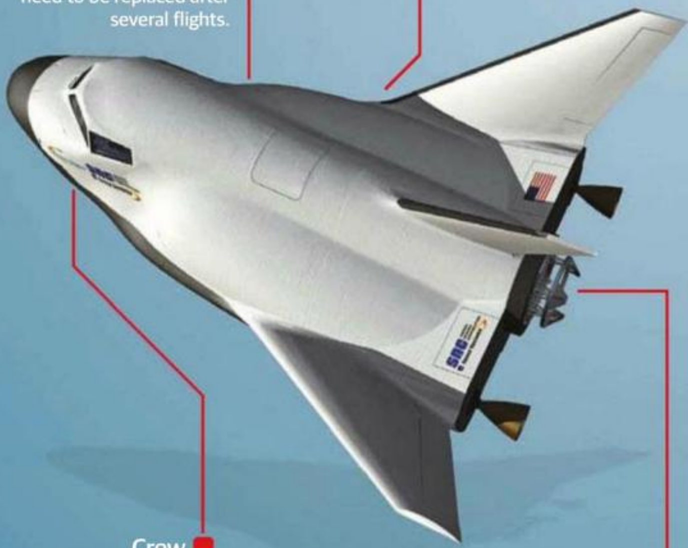
The Dream Chaser is a crewed space plane based on the HL-20 space taxi concept developed by NASA in the Eighties and Nineties, and is designed to carry humans into both sub-orbit and Low Earth Orbit.

As a space plane the Dream Chaser differs in design to Skylon and Lynx, which are both single-stage-to-orbit (SSTO) vehicles capable of taking off horizontally from a runway and landing in the same manner. Instead, Dream Chaser is a vertical-take-off, horizontal-landing (VTHL) space plane, designed to launch atop the nose of a conventional rocket, before gliding back to Earth in much the same way NASA's Space Shuttle did. Unlike the Space Shuttle, though, Dream Chaser carries no hazardous fuel and does not need to be decontaminated, therefore greatly reducing the time between flights. Aside from the rocket it launches on it will have its own propulsion in the form of SNC's hybrid rocket motor technology which will power it once it reaches orbit.

Dream Chaser is primarily being designed to travel to the ISS to collect cargo. However, it will also be able to carry humans.

Later this year it will perform unmanned atmospheric drop-tests, when it will be carried into the sky by Virgin Galactic's WhiteKnightTwo mothership and dropped from a high altitude to test its gliding capabilities. If it manages to stay on schedule, Dream Chaser will launch into orbit on an Atlas V rocket in 2014.

Dream Chaser will launch on an Atlas V rocket

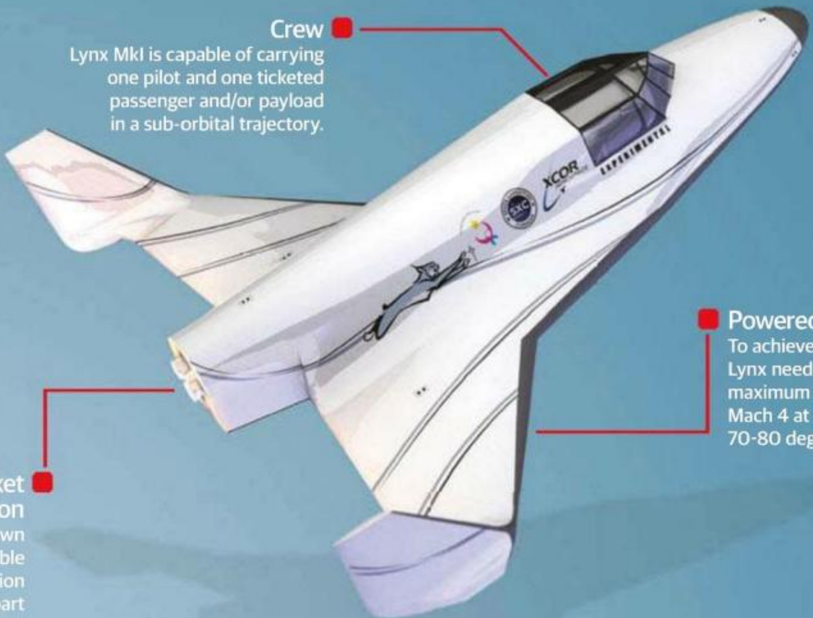


**Thermal protection system**
These ablative tiles would be replaced as a large group rather than tile by tile, and would only need to be replaced after several flights.

**Glide to land**
The vehicle will return from space by gliding with a low-g re-entry of under 1.5gs, protecting crew and science experiment return samples.

**Crew**
Dream Chaser is designed to carry between two and seven people and/or cargo to orbital destinations such as the ISS.

**Reaction control system**
These thrusters burn ethanol-based fuel which is not an explosively volatile material, allowing the Dream Chaser to be handled immediately after landing.



**Crew**

Lynx MkI is capable of carrying one pilot and one ticketed passenger and/or payload in a sub-orbital trajectory.

**Powered ascent**

To achieve sub-orbit the Lynx needs to reach a maximum airspeed of Mach 4 at a climb of 70-80 degrees.

**Rocket propulsion**

Lynx uses its own fully reusable rocket propulsion system to depart from a runway and return safely.

# Lynx

## Single-stage vehicle developed in California, USA

**Company:** XCOR (US)
**Launch date:** Q4 2012
**Cost:** $10m **Length:** 9m (30ft)
**Wingspan:** 7.5m (24ft)

Lynx is a single-stage vehicle that will travel to space and back without using any single-use rocket boosters. One key difference between the two is that the first class of Lynx space planes will only be able to reach sub-orbit, not full orbit like Skylon. However, the smaller design of Lynx allows it to both take off and land on a conventional runway, rather than just the latter for Skylon.

To achieve sub-orbit Lynx must take a steep climb of 70-80 degrees, the optimal angle at which to get into space. Once in space it will be able to perform a variety of tasks. It has a payload bay on its top to deploy satellites into orbit. It could also be used as an observation platform, with a telescope in its payload bay used to observe stars, the Sun, Earth or another celestial body.

Upon its return from sub-orbit, XCOR - the company behind Lynx - expects the space plane to have a turnaround time of just 35 minutes before it can fly again, compared to several weeks for NASA's Space Shuttle. Up to eight flights a day are possible with this configuration.

The fuels used by Lynx are non-toxic, which also helps keep the turnaround time to a minimum. This is because when Lynx lands it doesn't need to go through extensive restoration and decontamination, again a disadvantage of NASA's Space Shuttle and one that often took weeks or even months to sort out.

Lynx is expected to make a test flight before the end of 2012 and begin operational flights before the end of the decade. XCOR also has plans to create an orbital class of Lynx vehicles as opposed to just sub-orbit. This new class will be a two-stage-to-orbit vehicle. An orbital spacecraft using Lynx technology would fly on top of a larger first stage vehicle and, once a reasonable altitude had been reached, it would detach and fire its own engines to reach Low Earth Orbit while the first stage would return safely to Earth.

> "To achieve sub-orbit Lynx must take a steep climb, roughly 70-80 degrees, the optimal angle at which to get into space"

The Lynx MkI has a Primary Internal Payload of up to 120kg

# BLAST OFF! The most powerful rocket ever

Written by Amy Teitel

Capable of sending astronauts to the Moon and beyond, NASA's next shuttle, the Space Launch System, should be the rocket of the future, but odds of success aren't in its favour

The fact that NASA is currently without a means to take humans to orbit is to many a wonder in itself, but with the retirement of the Space Shuttle and the cancellation of the Constellation programme the US space agency is currently reliant on the Russian Soyuz craft to get astronauts to and from Low Earth Orbit (LEO). However, the ability to reach LEO, the Moon and even beyond will once again be restored to NASA in the shape of the Space Launch System, the largest and most powerful rocket ever seen. More powerful than the Saturn V that first took men to the Moon and more versatile than the Space Shuttle, the SLS is set to open up new frontiers in space exploration and make interplanetary travel a possibility once more. But that's only if the project can escape the political mire that may prove more of a challenge to its successful blast off than the pull of Earth's gravity.

Technically, the SLS is a mix of tried and tested rocket methodology and some groundbreaking engineering and materials, derived as it is from technology developed during the Space Transportation System programme - STS (aka the Shuttle) - and pieces of the current holder of the 'most powerful rocket ever' title, the Saturn V.

The basic elements of the SLS are its 64.6-metre (212.2 foot) expendable core stage on top of which its payload will sit. This core stage is based on the Shuttle's orange external tank flanked by two rocket boosters. The first SLSs will use the same boosters as the Shuttle and will be recovered and reused after launch while later versions plan to use lighter, expendable boosters. The first iteration

The J-2X engine is an upgrade on the J-2 engine used on the Saturn V

of SLS is the Block 1 configuration that stands 97.5 metres (319.8 feet) tall and will weigh 2.5 million kilograms (5.5 million pounds) at launch. The core stage is powered by four RS-25D engines, left-overs from the Space Shuttle programme that will be repurposed for the new heavy-lift successor. Weighing 3,545 kilograms (7,816 pounds) each, these engines use a mix of liquid hydrogen and liquid oxygen (LH2/LOX) as fuel and are designed to fire between 65 per cent and 109 per cent thrust. Once NASA's store of RS-25D engines is expended, the agency will replace them with the upgraded RS-25E engines. These larger versions weigh 3,699 kilograms (8,156 pounds) each and fire at 65 to 111 per cent thrust during launch.

The four core stage engines will use the thrust vector control technology held over from the Shuttle programme that allows each to rotate eight degrees on a gimbal mount. By diverting the rocket's thrust this way, the engines control its ascent and guide the rocket to its desired orbit. The Block 1 boosters are the same as those used for the Shuttle. Each booster's motor will burn through solid Ammonium Perchlorate Composite Propellant fuel.

In total, the Block 1 configuration core stage and boosters will generate 3.8 million kilograms (8.4 million pounds) of thrust, ten per cent more than the Saturn V's 3.4 million kilograms (7.5 million pounds) of thrust. With this power, SLS will deliver up to 70 metric tons into Earth orbit. Its payload will be the Orion Multi Purpose Crew Vehicle mated to an interim cryogenic propulsion stage or 'kick' stage, or cargo sent to the International Space Station (ISS).

The next progression is the Block 1A configuration which again will be powered by RS-25D engines or RS-25E engines dependent on NASA stock levels. This practice of using existing resources is central to the policies surrounding the project as handed down by Congress and covered later in this article. The Block 1A version stands at 95.7 metres (314.2 feet) tall in its cargo configuration and 97.8 metres (320.9 feet) in its crew configuration.

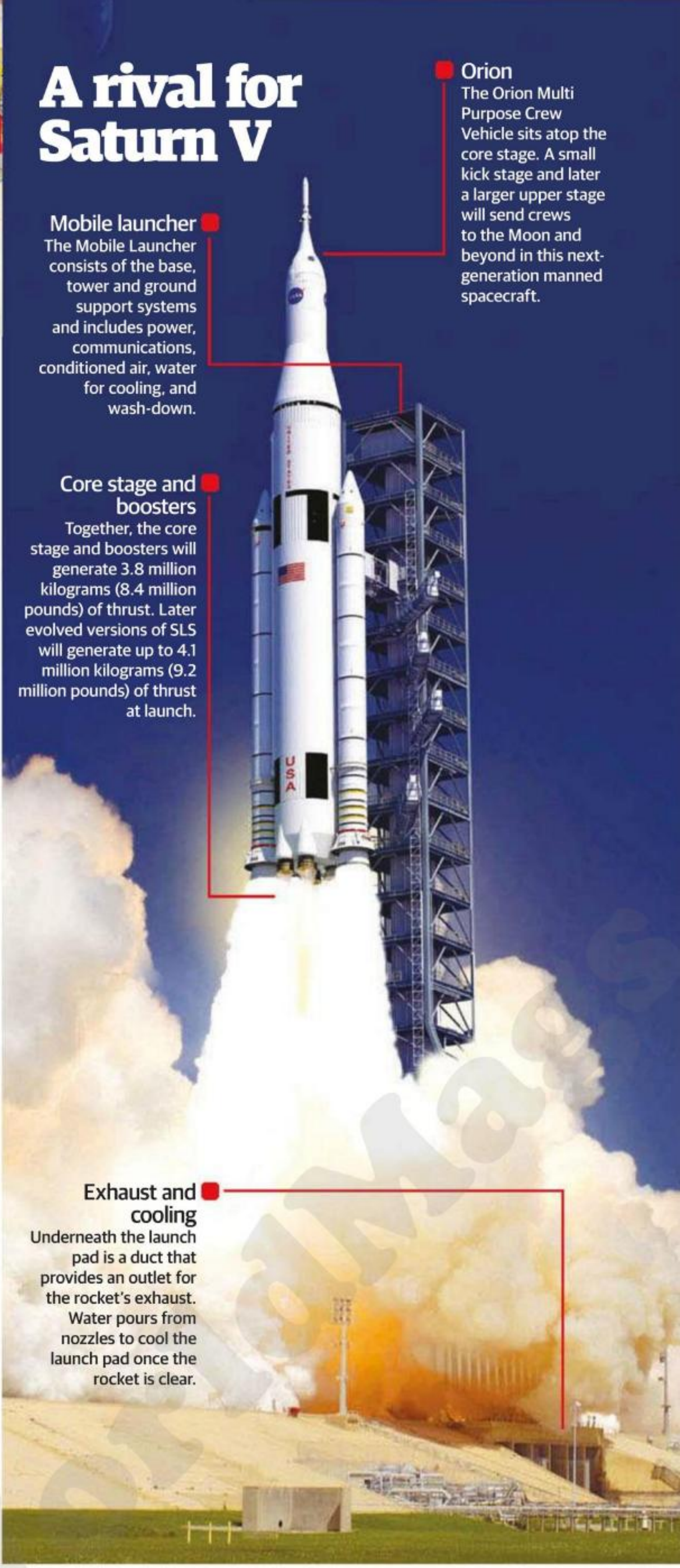
So with ten per cent more thrust than the Saturn V, the initial configurations of the SLS are already a wonder of technological achievement. But this will be far surpassed by the Block 2 version or the 'evolved SLS' which will dwarf both the Block 1 and Block 1A versions and the Saturn V itself. Four or five of the new RS25-E engines will power the core stage of Block 2 which will also feature an upper stage powered by two J-2X engines. These are descendants of the J-2 engine that powered the Saturn V's second SIV-B stage. Each engine weighs 2,500 kilograms (5,400 pounds) and will fire at 100 per cent of its maximum thrust power to send a payload beyond Earth's orbit.

In its crew configuration, Block 2 stands 115.3 metres (378.5 feet) tall and in its payload configuration it's 117.1 metres (384.3 feet) tall compared to Saturn V's 110 metres (363 feet). The core stage and boosters together will produce 4.1 million kilograms (9.2 million pounds) of thrust to lift 130 metric tons into orbit. This is also the first version that will be designed for the possibility of launching something else into orbit besides Orion and cargo.

SLS is designed to be a strong and resilient rocket. It has strength and stability in its unpressurised state and it can stay stacked on the launch pad for up to 200 days and go through up to 13 cryogenic fuelling cycles before wear becomes an issue. This will enable SLS to support a minimal number of launches per year.

Current estimates on SLS's cost, from the time of its announcement to its first launch in 2017, put the price tag around $10 billion USD - the programme will cost a total of $17 billion USD with Orion costing $7 billion. Early estimates suggest that development costs will be between $41.4 billion USD and $62.5 billion for the smaller Block 1 and Block 1A configurations.

## A rival for Saturn V



**Orion**
The Orion Multi Purpose Crew Vehicle sits atop the core stage. A small kick stage and later a larger upper stage will send crews to the Moon and beyond in this next-generation manned spacecraft.

**Mobile launcher**
The Mobile Launcher consists of the base, tower and ground support systems and includes power, communications, conditioned air, water for cooling, and wash-down.

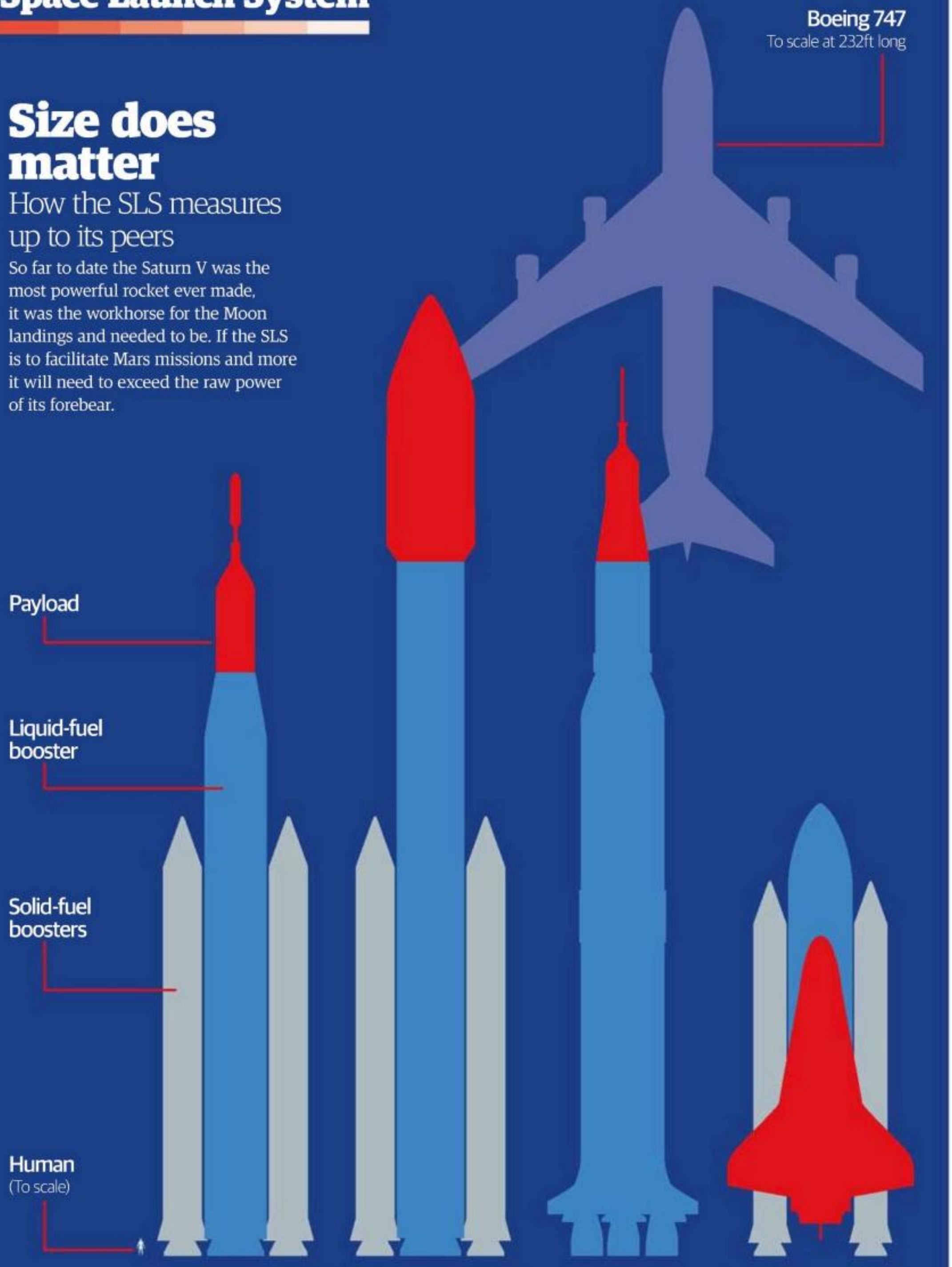
**Core stage and boosters**
Together, the core stage and boosters will generate 3.8 million kilograms (8.4 million pounds) of thrust. Later evolved versions of SLS will generate up to 4.1 million kilograms (9.2 million pounds) of thrust at launch.

**Exhaust and cooling**
Underneath the launch pad is a duct that provides an outlet for the rocket's exhaust. Water pours from nozzles to cool the launch pad once the rocket is clear.

# Size does matter

## How the SLS measures up to its peers

So far to date the Saturn V was the most powerful rocket ever made, it was the workhorse for the Moon landings and needed to be. If the SLS is to facilitate Mars missions and more it will need to exceed the raw power of its forebear.



| | SLS - initial configuration | SLS - final configuration | Saturn V | Space Shuttle |
|---|---|---|---|---|
| **Years of operation** | First launch planned for 2017 | To be determined | 1967-1973 | 1981-2011 |
| **Destinations** | Earth orbit, deep space | Deep space, asteroids, Moon, Mars | Earth orbit, Moon | Low Earth Orbit |
| **Fuel type** | Solid fuel, LH2/LOX | Solid fuel, LH2/LOX | Kerosine, LH2/LOX | Solid fuel, LH2/LOX |
| **Height** | 97.5 metres (319.8ft) | 115.3 metres (378.5ft) | 110 metres (363ft) | 56 metres (184ft) |
| **Lift capability** | 70-77 metric tons | Up to 130 metric tons | 118 metric tons | 24.4 metric tons |

The first SLS mission is scheduled to launch on 17 December 2017. A Block 1 configuration will put an unmanned Orion into Earth's orbit before a kick stage sends it to the Moon. The next mission, currently slated some time in 2019, will send astronauts on the same free-return trip to the Moon. So far, those are NASA's only concrete plans, but tentative missions are emerging. Preliminary reports suggest NASA will launch one SLS each year, alternating between manned and unmanned missions.

Long-range plans seem to have astronauts returning to the Moon before reaching and possibly landing on a near Earth asteroid. There is also some interest in SLS launching a mission to one of the five Lagrange points in Earth's orbit, a point where the gravity from the Earth and Moon exert an equal pull on an object so it remains stationary relative to both bodies. Some proponents of a manned mission to Mars see a prolonged stay at a Lagrange point as a good dress rehearsal for a manned mission to Mars, which is SLS's ultimate goal. The timeline for these missions is hazy, but a mission to Mars is unlikely to launch before the mid-2030s.

At first glance, SLS seems like the perfect rocket - more versatile, powerful and durable than anything that has preceded it. But there are major threats looming over the rocket. There's a chance SLS could get stuck as a ferry between the US and the ISS. It is NASA's hope that the commercial sector will take over Low Earth Orbital launches, but Block 1 SLS flights would be preferred to a continued reliance on the Russian Space Agency in the event that no commercial option is viable.

The cost of SLS launches could prove prohibitive. Refurbishing and reusing the solid boosters of the Block 1A configuration is expected to cost about 80 per cent as much as building new boosters for each launch. Once the second generation of expendable boosters is introduced, no part of the rocket will be reused. This makes costs per launch extremely high.

Early estimates suggest it will cost between $8,500 and $10,000 to deliver 0.45 kilograms (one pound) into Low Earth Orbit with SLS. That equates to an overall launch cost of $1.3 billion USD for the 70-ton payload and $2.45 billion USD for the 130-ton version. With all the necessary launch support, SLS is on track to cost about $5 billion USD per launch; the Shuttle cost $1.5 billion and the Saturn V $1.17 billion adjusted for inflation.

Core components of the J-2X engine installed on the A-1 Test Stand at NASA's Stennis Space Center near Bay St Louis, Mississippi

Critics have slammed SLS for its high costs, saying it's sapping money needed for other programmes. When NASA's budget for FY 2013 was released, funding for SLS fell from $1.502 billion USD to $1.34 billion. But this drop pales in comparison to the Mars exploration programme that lost $318 million USD.

Funding for NASA's programmes comes from US Congress, and the political aspect poses the biggest threat to SLS. The Orion and SLS are the two surviving pieces of the Constellation programme that began under President Bush Jr before its cancellation by President Obama. After sparing SLS, Congress began making demands and setting parameters. Congress has even had a hand in determining who will build each piece of the rocket. The involvement of lawmakers has led some critics to call SLS a job-retention programme disguised as a rocket.

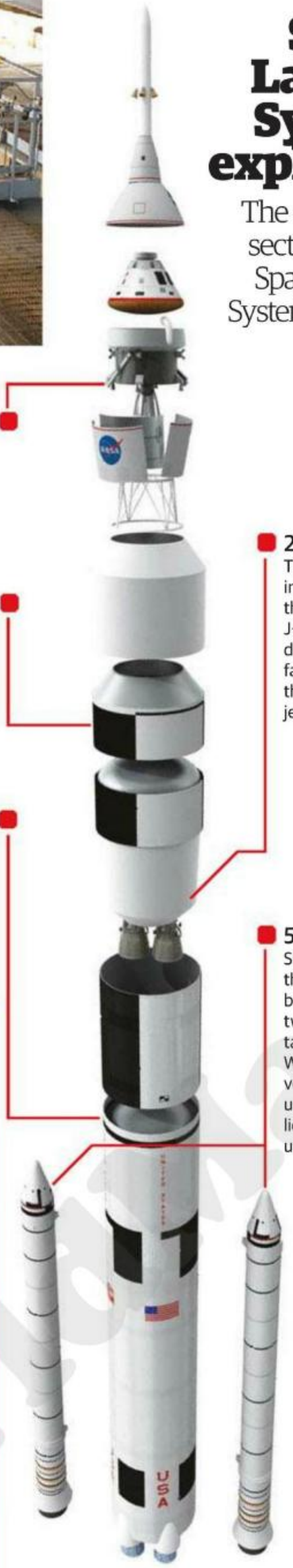
Within the high cost of SLS's development and launch is its lack of defined goals. It's clear from the wavering US congressional support that there is no commonly agreed upon endpoint for SLS, and this could prove devastating. Part of the Saturn V's success came from the nation rallying behind the need to put a man on the Moon. Without a common goal, SLS is unlikely to get the support it needs to move through to completion.

In many ways the odds seem stacked against the SLS. Wavering congressional support could result in further cuts, but SLS could gain funding with a different congressional group. The best-case scenario is for NASA to have SLS on hand to send men and robotic missions further into the Solar System unravelling cosmic mysteries for all mankind. ●

*Greatest rocket ever or cosmic dud? Join the discussion @spaceanswers #SLS*

# Space Launch System exploded

The stages and sections of the Space Launch System revealed



**1. Spacecraft adapter**
The adapter attaches the manned vehicle to the rocket during launch.

**2. Interstage**
The hollow interstage houses the upper stage J-2X engines during launch and falls away when the core stage jettisons.

**3. Instrument Unit**
The Instrument Unit contains guidance and electronics that control the rocket's launch angle.

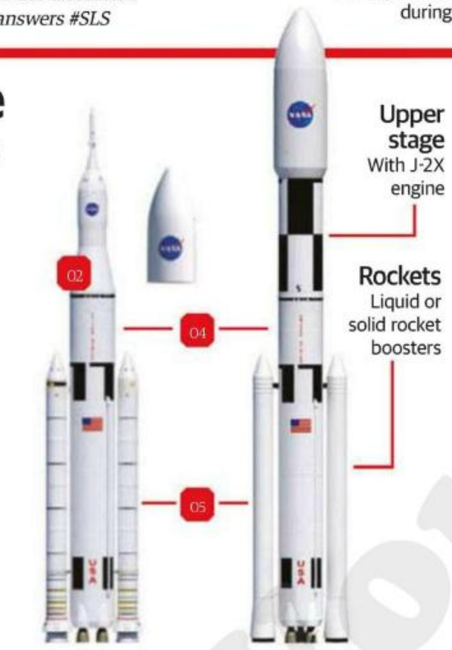
**4. Core Stage**
The same diameter as the Space Shuttle's external fuel tank, this stage uses four or five RS-25D/E engines to burn through LH2/LOX fuel during launch.

**5. Boosters**
Similar to the Shuttle's boosters, these two strap-on tanks are longer. Whether future versions will use solid or liquid fuel is still undetermined.

## SLS architecture

A cornucopia of configurations make for a versatile vehicle

SLS's initial configuration will develop into a bigger and more powerful rocket with subsequent versions. In its first configuration, the rocket is smaller with just the core stage with four RS-25D engines recycled from the Shuttle. Two solid fuel boosters flank the core stage. An Orion crew capsule or a cargo payload sits on top. The evolved SLS takes the same model but adds more power, bigger engines, and an upper stage to send astronauts and payload further into the Solar System. RS-25E engines replace the D version on the core stage giving it more power, and the flanking boosters may be solid or liquid fuelled. The upper stage is powered by two J-2X engines, advanced versions of the engines that powered the Saturn V's SIV-B stage.



**Initial capability 2017-21** **Evolved capability post-2021**

WorldMags

# The solar cycle

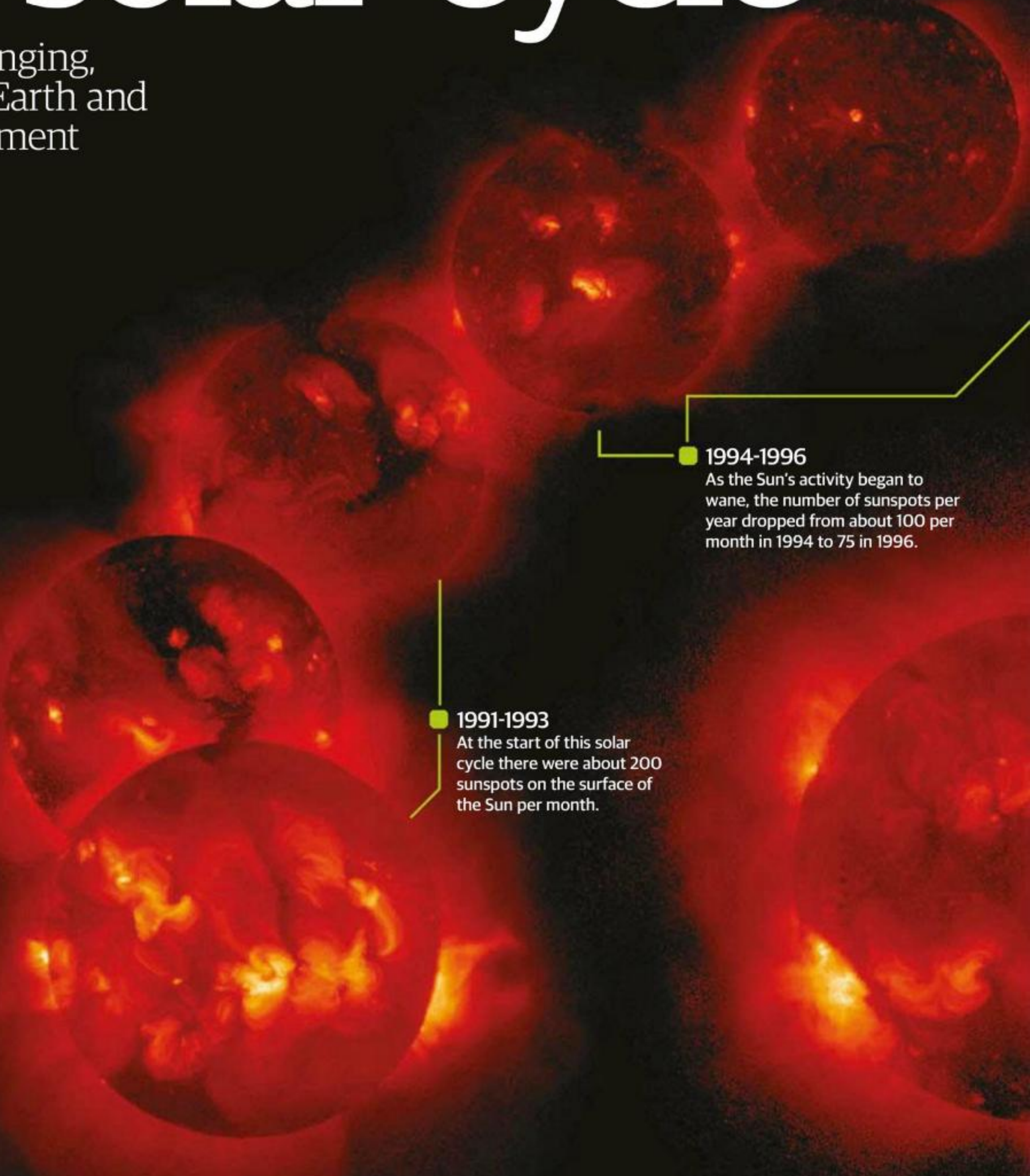
## Our Sun is ever-changing, affecting all life on Earth and our natural environment

Our Sun may be a great distance away but its fluctuations and perturbations are still felt here on Earth.

Every 11 years the Sun moves from a period of low activity, known as a solar minimum, to a period of high activity, known as a solar maximum, and back again. When it is at its most active the Sun is even more violent than usual, with a greater number of sunspots appearing on its surface and therefore more solar flares emitted into space. During its minimum point it is still a raging inferno firing material into space but, by comparison, it is much quieter and sunspots, and therefore solar storms, are rare.

Cycles are observed by monitoring the frequency and position of sunspots on the Sun. When the Sun reaches the end of its cycle, new sunspots will appear near the equator. The beginning of the next cycle will see sunspots appear at higher latitudes on the surface of the Sun.

Solar cycles have been observed for centuries, but a standardised method of counting them was not devised until 1848 when Johann Rudolf Wolf started counting sunspots on the solar disk and calculated the Wolf number, which is still used today to keep track of the solar cycle. Cycles vary in their intensity. From 1645 to 1715 there were few sunspots present on the Sun, a period known as the Maunder Minimum. The number of sunspots has been relatively more uniform this century, with cycles having an average period of 10.5 years. The Sun also has a 22-year magnetic cycle where, every 22 years, its magnetic field flips from pole to pole. This doesn't have a noticeable effect on the Solar System, but indicates when the solar maximum of the current cycle has been reached. However, the reason for these cycles remains a mystery. No one yet has any clear understanding as to why the Sun has periods of varying activity.



**1994-1996**
As the Sun's activity began to wane, the number of sunspots per year dropped from about 100 per month in 1994 to 75 in 1996.

**1991-1993**
At the start of this solar cycle there were about 200 sunspots on the surface of the Sun per month.

**10 years of the Sun**

These X-ray images were taken by Japan's Yohkoh Solar Observatory and show the changes in the Sun's corona over a ten-year cycle between 30 August 1991 and 6 September 2001

> "Solar cycles have been observed for centuries, but a method of counting them was not devised until 1848"

**1997-1998**
The Sun reached its period of solar minimum between these years, falling to almost zero sunspots per month.

**1999-2001**
The Sun's activity increased again to a solar maximum, with up to 175 sunspots appearing per month.

**The Scientist's view**

### How we understand solar cycles

"Sun-Earth interaction is complex, and we haven't yet discovered all the consequences of solar cycle variation on Earth's environment. We saw a large amount of geomagnetic activity driven by recurring fast solar wind streams during the recent solar minimum. A surprising departure from the consistently low activity we'd come to expect from previous minima, especially considering the record low level of sunspots. These new observations deepen our understanding of how solar quiet intervals affect the Earth and how and why this might change from cycle to cycle."

**Sarah Gibson, UCAR, @AtmosNews**

## The sun by numbers

Fantastic figures and surprising statistics about our nearest star

**99.86%**
*The Sun's percentage of mass of the entire Solar System*

**Less than 5%** of stars in the Milky Way are brighter or larger than the Sun

**1 million Earths**
Would fit inside the Sun

***164 watts*** *Is the amount of energy every square metre of the Earth's surface receives. That's the equivalent of a 150-watt table lamp on every square metre of the Earth's surface*

**498 seconds**
How long it takes light to travel from the Sun

***100 BILLION***
TONS of dynamite would have to be detonated every second to match the energy produced by the Sun

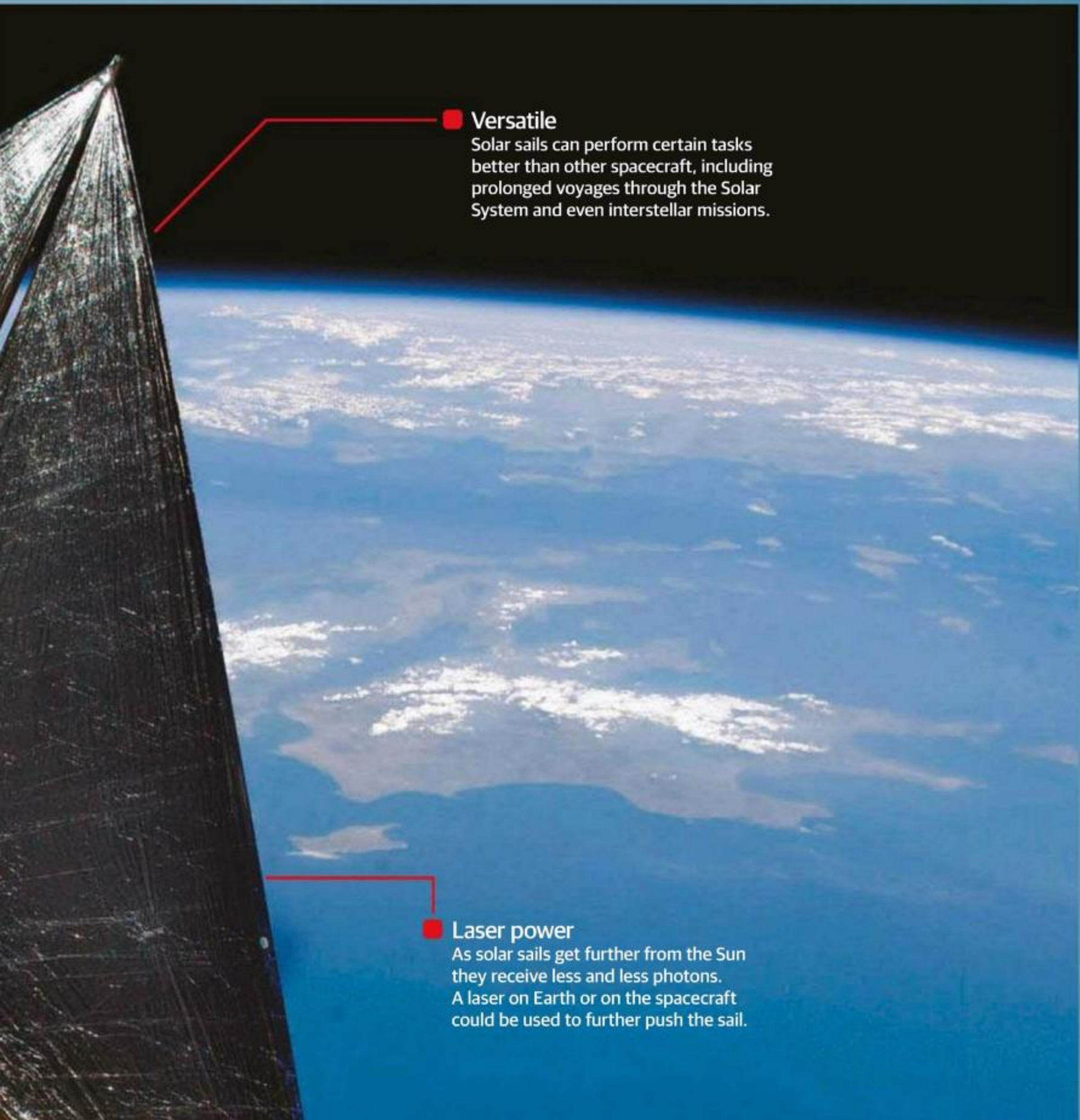
# Solar sails

## Will humanity ever breeze through the cosmos?

**Written by Jonathan O'Callaghan**

**Speed**
Solar sails can theoretically reach speeds unmatched by modern chemical spacecraft. To slow down, the sail can be tilted to reflect the sunlight in such a way that deceleration occurs.

**Uses**
Solar sails could be used for a variety of missions including deep space expeditions, de-orbiting man-made Earth satellites or putting a spacecraft into a stationary orbit above the Sun, Earth or another body.



**Versatile**
Solar sails can perform certain tasks better than other spacecraft, including prolonged voyages through the Solar System and even interstellar missions.

**Laser power**
As solar sails get further from the Sun they receive less and less photons. A laser on Earth or on the spacecraft could be used to further push the sail.

For decades we've sought to find better and more powerful types of fuel to allow us to explore the cosmos. From primitive kerosene-based rocket fuels to modern day liquid hydrogen and oxygen engines, and from chemical engines to long-lasting ion drives, our methods of producing more powerful rockets have come on leaps and bounds. But could it really be that the answer to future space exploration is the same method used by our ancestors to venture into strange new lands on Earth: the sail?

Solar sails work by using the influence of the Sun. Our Solar System's star emits photons that produce a tiny force when they come into contact with another object. This small force is incredibly minute but, over time and given that space is a frictionless vacuum, it can slowly push a small object like a spacecraft faster and faster.

In theory, a giant solar sail would take about 100 days to reach 16,000kph (10,000mph). It could accelerate to 58,000kph (36,000mph) in one year, and in three years it could travel over 160,000kph (100,000mph). While the latter is still only 0.015 the speed of light, at this speed you could reach Pluto from Earth in under five years, compared to the nine-year journey time for humanity's current fastest chemical propulsion spacecraft, New Horizons.

Several solar sail concepts have already flown, including Japan's successful 2010 spacecraft IKAROS and now NASA is planning a 1,200 square-metre solar sail for late 2014 under the direction of L'Garde in Tustin, California. The aim of this solar sail will be to demonstrate an early warning system for solar flares. Between the Earth and the Sun is an area known as Lagrange point 1 where the gravity of the Sun and Earth are equal, allowing spacecraft to remain at a stationary position relative to the Sun and the Earth. This solar sail spacecraft will create an artificial Lagrange point about twice as close to the Sun. By using the photons emitted from the Sun as radiation the solar sail-powered spacecraft will be able to sit much closer to the Sun as it will have a constant force pushing it away from the Sun which, combined with the gravity of Earth, would balance out the gravity of the Sun. This could be very useful for providing an early warning system for a dangerous solar storm, and is just one of the many uses of solar sails that are currently being researched.

Solar sails could be used to propel spacecraft indefinitely in Earth orbit

The geysers of Enceladus fire out water, ice crystals and gases

# Giant ice geysers of Enceladus

Written by Shanna Freeman

## In 2005, NASA's Cassini spacecraft found huge plumes of water and ice shooting from the south polar regions of Saturn's sixth largest moon. But what are the causes and does it indicate life in our Solar System?

We think of moons as cold, dead satellites for a reason – we've yet to find signs of life anywhere else in our Solar System and a moon seems like the last place we'd look. However, after the Cassini spacecraft examined Enceladus – Saturn's sixth largest moon – we started to think differently.

Enceladus's southern polar region is covered with four or five 'tiger stripes' – parallel depressions in the lithosphere about 500m (1,600ft) deep, more than 100km (62 miles) long and a few kilometres wide. Officially called sulci, these cracks are probably caused by a process called cryovolcanism. Just as volcanoes on Earth spew molten rock, Enceladus is spraying water, ice crystals and gases from geysers located in these cracks.

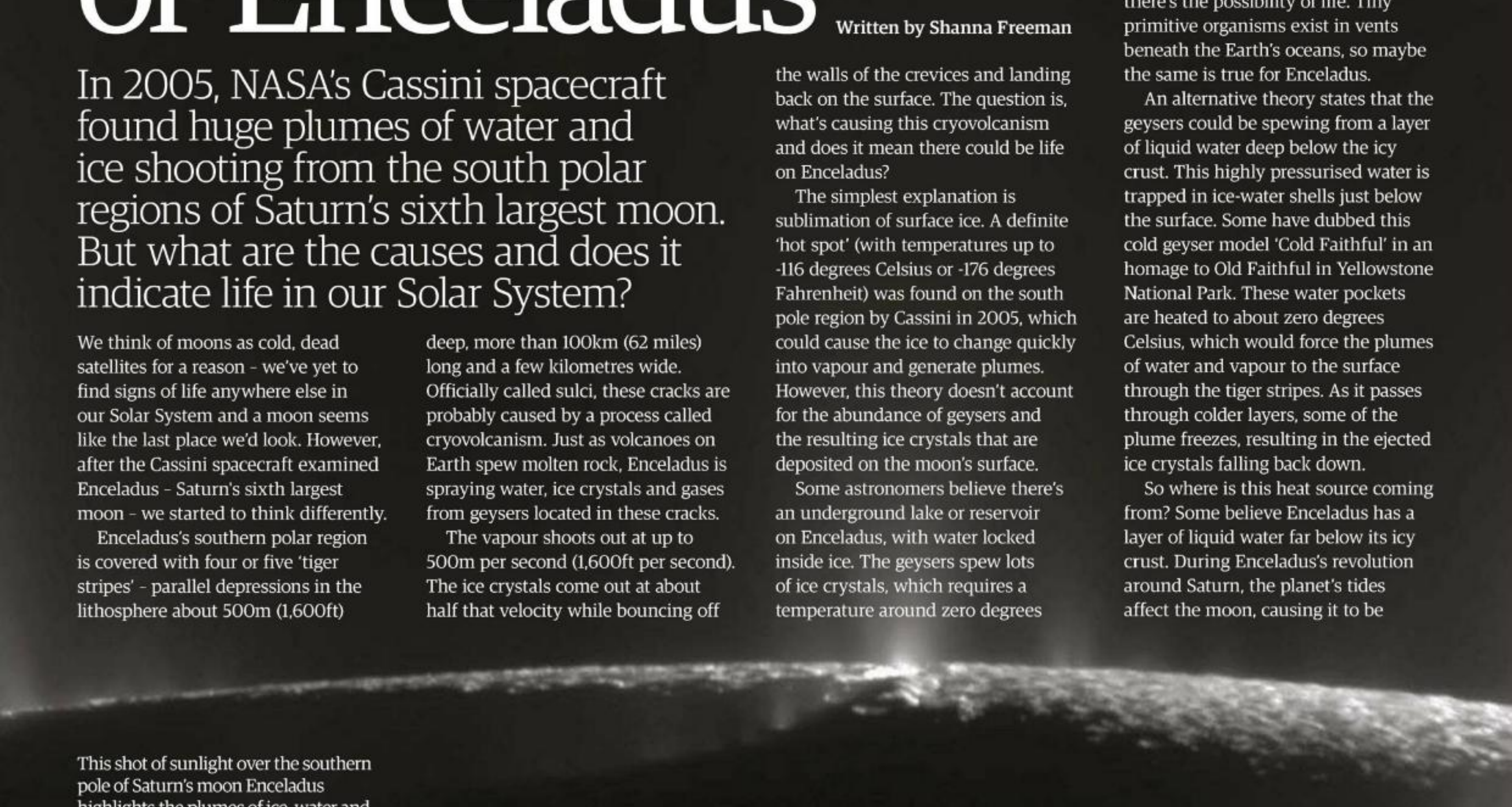
The vapour shoots out at up to 500m per second (1,600ft per second). The ice crystals come out at about half that velocity while bouncing off the walls of the crevices and landing back on the surface. The question is, what's causing this cryovolcanism and does it mean there could be life on Enceladus?

The simplest explanation is sublimation of surface ice. A definite 'hot spot' (with temperatures up to -116 degrees Celsius or -176 degrees Fahrenheit) was found on the south pole region by Cassini in 2005, which could cause the ice to change quickly into vapour and generate plumes. However, this theory doesn't account for the abundance of geysers and the resulting ice crystals that are deposited on the moon's surface.

Some astronomers believe there's an underground lake or reservoir on Enceladus, with water locked inside ice. The geysers spew lots of ice crystals, which requires a temperature around zero degrees Celsius (32 degrees Fahrenheit). In an underground lake, ice, water and vapour would all mix together. Expanding vapour could escape through the tiger stripes, cooling and causing ice crystals to condense. Where there's a large amount of water, there's the possibility of life. Tiny primitive organisms exist in vents beneath the Earth's oceans, so maybe the same is true for Enceladus.

An alternative theory states that the geysers could be spewing from a layer of liquid water deep below the icy crust. This highly pressurised water is trapped in ice-water shells just below the surface. Some have dubbed this cold geyser model 'Cold Faithful' in an homage to Old Faithful in Yellowstone National Park. These water pockets are heated to about zero degrees Celsius, which would force the plumes of water and vapour to the surface through the tiger stripes. As it passes through colder layers, some of the plume freezes, resulting in the ejected ice crystals falling back down.

So where is this heat source coming from? Some believe Enceladus has a layer of liquid water far below its icy crust. During Enceladus's revolution around Saturn, the planet's tides affect the moon, causing it to be

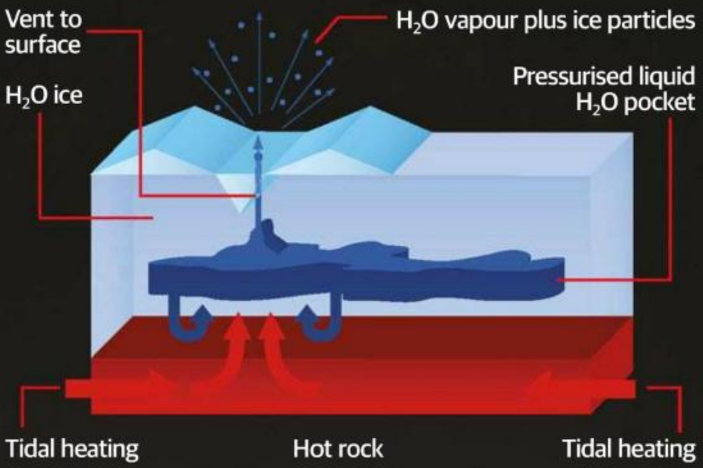


This shot of sunlight over the southern pole of Saturn's moon Enceladus highlights the plumes of ice, water and chemicals spewing from its surface

## Theory 1

### A planet that runs hot and cold makes for an explosive effect, says one theory

One theory for the cause of these geysers posits that the moon has a much hotter core, which heats highly pressurised liquid water caches just under the surface. When the water gets above zero degrees Celsius (32 degrees Fahrenheit), it jets through the 'tiger stripe' fractures. As the water rises, it passes through layers of ice as cold as -350 degrees Celsius (-598 degrees Fahrenheit), cooling along the way. Jets of water, ice and particles blast through the cracks, with most of the ice landing back on Enceladus's surface.


Vent to surface
$H_2O$ vapour plus ice particles
$H_2O$ ice
Pressurised liquid $H_2O$ pocket
Tidal heating
Hot rock
Tidal heating

squeezed and pulled apart. These forces cause faults on Enceladus to rub against each other and this movement may be as much as half a metre over the tidal period. The resulting friction melts the ice layer into a water layer leading to the cryovolcanic activity. Still further modelling has refined the cold geyser 'Cold Faithful' model into a colder 'Frigid Faithful' model. In this model, the geysers spew due to explosive decompression of clathrates - gases like methane and nitrogen that are trapped in ice-like structures - located just below the surface. A source of heat just 40 degrees Celsius (104 degrees Fahrenheit) warmer than the moon's average temperature could've been enough to cause the icy surface to crack and form the stripes. These cracked shells expose more clathrates to heat, causing the released gases to rush up the vents, taking water and ice with them. If the Frigid Faithful model is accurate, the process doesn't need wild swings in temperature. It also means no underground reservoirs of liquid water, and therefore, nothing to sustain life.

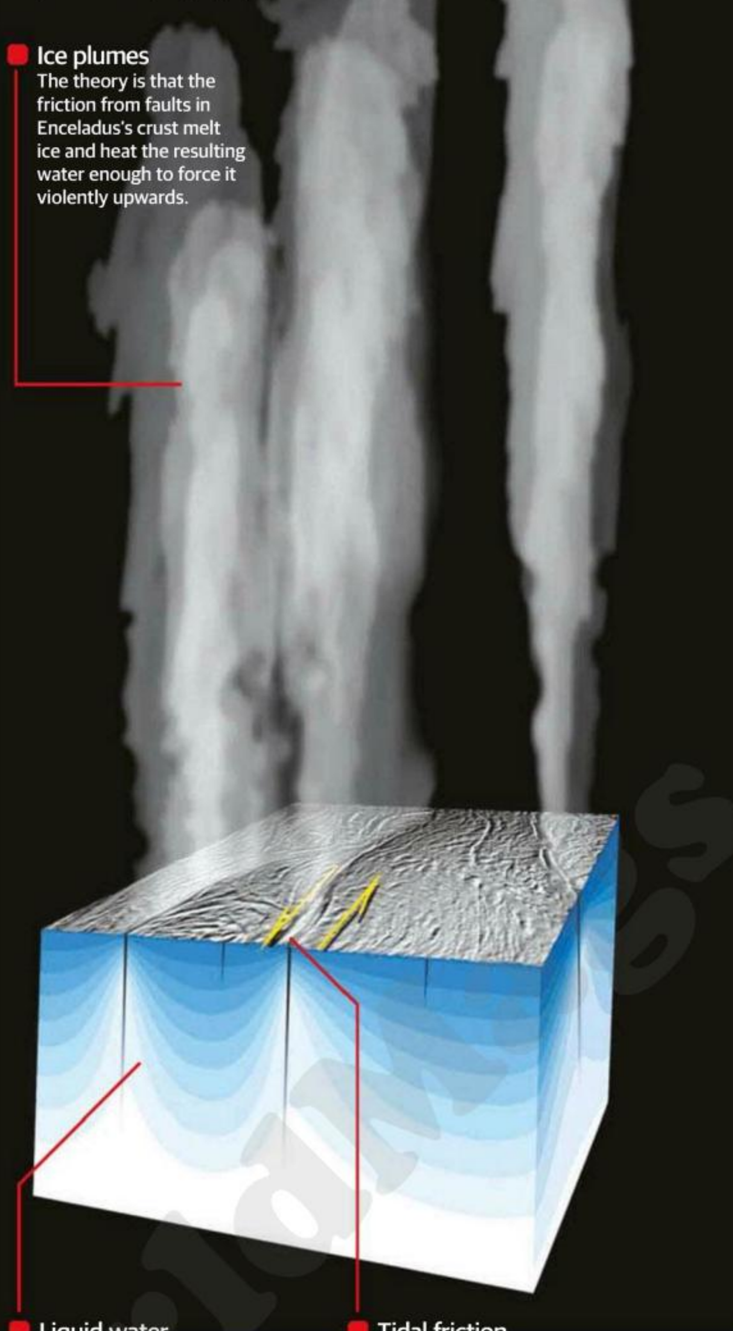
Proponents of the cold geyser model say the Frigid Faithful model doesn't account for the structures that appear to be frozen ice on the moon's surface, which would indicate liquid water. Nor do they explain the high saline content of the plumes close to the moon's surface, which suggests an 'underwater salty ocean'.

In 2011, scientists announced that this moon is still our best possibility for finding other life in our Solar System. The Cassini mission continues to send back images, but we have much more to learn about its make-up and the cause of its icy plumes before we can determine the true viability of finding life on a frozen moon.

***Tell us which theory you think is more viable and why @spaceanswers #Enceladus***

## Theory 2

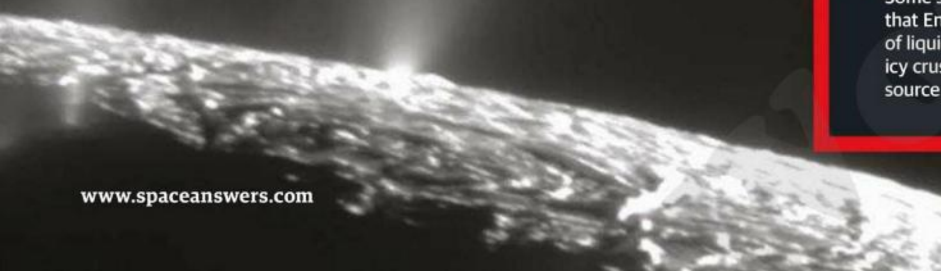
### Could friction prove the force behind Enceladus's mysterious, icy geysers



**Ice plumes**
The theory is that the friction from faults in Enceladus's crust melt ice and heat the resulting water enough to force it violently upwards.

**Liquid water**
Some scientists believe that Enceladus has a layer of liquid water far below its icy crust, which may be the source of the icy geysers.

**Tidal friction**
The moon is subjected to gravitational forces from Saturn and a nearby moon, which cause it to compress, contract and form cracks.



# Are there planets made of diamonds?

Scientists offer hope of finding diamond-based planets in our galactic backyard

Written by Shanna Freeman

In August 2011, a team of astronomers and researchers announced that they had made a most unusual finding. While using telescopes in the USA, England and Australia to explore the properties of a pulsar named J1719-1438, they noticed that the beams of radiation emitted regularly from this tiny spinning star were modulated in such a way as to indicate that the pulsar had a satellite. This newly discovered planet was about five times the diameter of the Earth, no more than 60,000 kilometres (37,000 miles). It was also very close to the pulsar, orbiting it in not much more than two hours. The mass of the planet was less than a few times the mass of Jupiter, and the short orbital period helped them to determine its radius. These two pieces of information led the team to conclude that the planet was also incredibly dense for its size. It couldn't be a gaseous planet like Jupiter, but made of heavier stuff...

We asked Dr Benjamin Stappers, a Reader with the Jodrell Bank Center for Astrophysics at the University of Manchester, to explain more about the planet's discovery. "If a pulsar's beam of radiation crosses the Earth then, using sensitive radio telescopes, a pulse of radio emission can be detected," he explained.

"If a pulsar is in a binary system with another star, or is being orbited by a planet, then the companion causes the pulsar to also move. This causes changes in the time of arrival of the pulses. By careful analysis we use these changes to work out the period of the orbit of the planet and other parameters of the binary system. The fact that we have a very dense object, likely crystalline in structure and consisting of carbon and oxygen, suggested that part of the planet may be similar to a diamond in nature."

> "Diamond planets form in much the same way that Earth formed, just from different starting materials"
>
> Dr Wendy Panero of Ohio State University

So how does a diamond planet form, and what might it look like? For starters, the planet orbiting J1719-1438 isn't a planet in the same sense that Jupiter or Earth is a planet. Instead, the researchers think it's actually the remains of another star. J1719-1438 is a millisecond pulsar - its rotation is just a few milliseconds long as opposed to a normal pulsar rotation of one second. Originally, it was probably part of a two-star, or binary system, but the pulsar pulled material from the other star and sped up over time. Astronomers have seen this type of behaviour in other binary systems, but J1719-1438 and its orbiting planet are different. Sometimes the process eats away or totally destroys the other star. The planet is a white dwarf that's missing 99 per cent of its mass, but it's not currently being stripped by the pulsar. This system is known as an ultra-compact low mass X-ray binary system. There's no way to tell what it looks like, but it's probably spherical.

If you're picturing a sparkling, princess-cut gemstone out in deep space, think again - we're talking very rough and raw crystalline carbon here. While the team was exploring the pulsar and its 'diamond planet', researchers at Ohio State University were experimenting to discover how diamonds form on Earth. Dr Wendy Panero and her team applied high pressures and temperatures to small amounts of minerals like iron, carbon and oxygen under microscopes.

Next, they created computer models of planets with more carbon content than Earth - diamond planets - and discovered that these planets may grow just as Earth does. According to Dr Panero, they posited that "diamond planets form in much the same way that Earth formed, just from a different mix of starting materials. Earth has a significant amount of iron, oxygen and silicon because it formed around a star with an abundance of these elements." There are stars with a different mix of starting ingredients, and therefore the planets that form about them will have different compositions.

These theoretical diamond planets wouldn't be pretty and sparkly, either; the diamonds would be part of a mixture of minerals and "dirty." Dr Panero states that they wouldn't "be as plentiful as planets like Jupiter or Earth, but they should exist."

So yes, there probably are diamond planets - either the remains of stars or heavily carbon-based planets that form like Earth. But don't start thinking that there's a new source of the coveted gemstone just yet. ●

## Other types of planet

### Could other bizarre worlds exist in the universe?

Diamond planets aren't the only amazing worlds that might exist in the universe. We've barely scratched the surface of planet hunting outside the Solar System but early indications suggest that there could be a multitude of bizarre and incredible new worlds.

Planets such as Mars and Mercury have demonstrated that a planet can be predominantly ruled by one type of ecosystem. This makes it possible that some types of planets might be large balls of a particular type of material, be they purely made of carbon, water, iron or something else. In fact, astronomers at NASA have come up with various models for what characteristics they would expect different types of planets to have if they were indeed largely made up of one substance alone. For example, a planet the same mass as Earth but made of mostly pure water would be 15,000km in diameter compared to just under 13,000km across for Earth (which itself is made of mostly silicate rock), while a pure iron planet of the same mass would only be 4,800km in diameter.

*Let us know what other types of planet you think we might find @spaceanswers #newworlds*

## How a diamond planet forms

Take some oxygen, some carbon and a pulsar

**1. Binary system**
In this binary system, a small, spinning star called a pulsar gradually siphons off materials from its orbiting star. This leads to the pulsar's rotation increasing in speed until it becomes a millisecond pulsar.

**2. Losing mass**
The star loses most of its mass, with nothing but carbon and oxygen left behind. Most of its mass is pure diamond, and it is the same size as Jupiter but much denser.